2.737 Mechatronics
Laboratory Assignment 3: Electronic Scale

Assigned: 10/14/14
Pre-lab due: Friday 10/17/14 online by 5pm
Reports due: Thursday/Friday 10/23–10/24/14 in checkoffs

1 Overview

In this lab you will design and implement circuitry for interfacing with an electronic scale using an instrumentation amplifier and precision voltage reference. The scale is based upon a beam with bonded foil strain gages in a full-bridge configuration. The instrumentation amplifier is used to amplify the millivolt range bridge output voltages up to the range of volts for interfacing with the myRIO A/D convertor. You will also look at the measurement of signals in the presence of *common-mode* voltage disturbances.

2 Prelab and Lab Reports

Your *prelab* calculations are due in a prelab report to be submitted by 5pm on Friday 10/17. For the prelab, please complete all the requested modeling, preliminary measurements, circuit design parameter choices, etc. You will need to make a copy to give to us, and keep your original to support the lab portion of the assignment. You may submit these online, or in the filing cabinet in the lab. It is not permitted to look at other students' prelab reports in the filing cabinet.

The *lab report* should clearly document your experimental work, predictions, results, and a comparison between these, with explanations of observed phenomena and discrepancies. Be sure to show us your *understanding* of the lab and design experiences. No formal lab report structure is required. The lab report is due at the time of your checkoff. Please also include the prelab copy with this report. These must be submitted in paper format at the checkoff.

You will also schedule a *lab checkoff* with the staff during 11/23–24. In this checkoff, you will need to be able to discuss your design process, calculations, and experimental results. We are particularly interested in how you have used the experimental results to understand the ways in which the system matches predictions and the ways in which it departs from modeled behavior. Come to lab well ahead of your checkoff time so that you can get set up and have your system running at the start of checkoff.

3 Scale Interface Circuit

The scale mechanism uses a full-bridge strain gage circuit attached to a beam which supports the scale weighing platform. The circuit used for interfacing with the electronic scale is shown below in Fig. 1. Note that in this circuit, we use the letter S to indicate the myRIO board common, and the letter B to indicate the common for the strain gage bridge. This bridge common is driven by the signal generator to create an artificial common-mode disturbance, which is reflected in the common-mode of the bridge output voltages.

The scale is rated for about 3 kg maximum load. *Do not apply any loads higher than 3 kg as they may damage the scale mechanism.*

The full-bridge circuit uses four active strain gages configured as shown below in Fig. 2. The change in resistance is given by $\Delta R = R \cdot G.F. \cdot \epsilon$, where R is the nominal no-strain gage resistance, ϵ is the strain, and $G.F.$ is the *gage factor*. For metal foil strain gages, the gage factor is typically in the range of 2–5. Since our strain gage beam is taken from a commercial electronic scale, we are not given the gage factor or the gage resistance. We also do not know the relationship between strain and weight on the scale. We will experimentally determine the relationship between weight and bridge output voltage. Note also that in this simple model we are ignoring the effect of temperature on the gage resistance.

Note that the reference voltage is applied between terminals A and B, and the bridge output voltage is taken between terminals C and D, as indicated in the figure.

4 Prelab

1. **Bridge resistance:** Assume zero strain, and thus $\Delta R = 0$. In this condition, calculate the value of resistance measured: 1) between terminals A and C, 2) between terminals A and D? In the lab, use a multimeter to measure the resistance between these terminals. What is the nominal bridge resistance R?

2. **Bridge output voltage:** Write an expression for the bridge output voltage v_b given a 10 volt reference input, and assuming that the gage factor $G.F.$ is and unknown variable This expression should also be in terms of the nominal bridge resistance R and strain ϵ.

3. **Measured circuit output:** Now build *just* the reference voltage portion of the circuit, and ground the disturbance input terminal, *i.e.* don't connect the signal generator. Attach the scale cable to your circuit board and wire the reference circuit to the scale. Use the multimeter to measure the bridge voltage as a function of weight on the scale for several weights varying from zero to 2 kg. Write an expression for a linear model relationship between weight and output voltage.

4. **Differential amplifier design:** Using your measurements above, choose R_g so as to give 9 V output from the LT1167 to the A/D convertor for 2 kg load on the scale. Show your calculations.

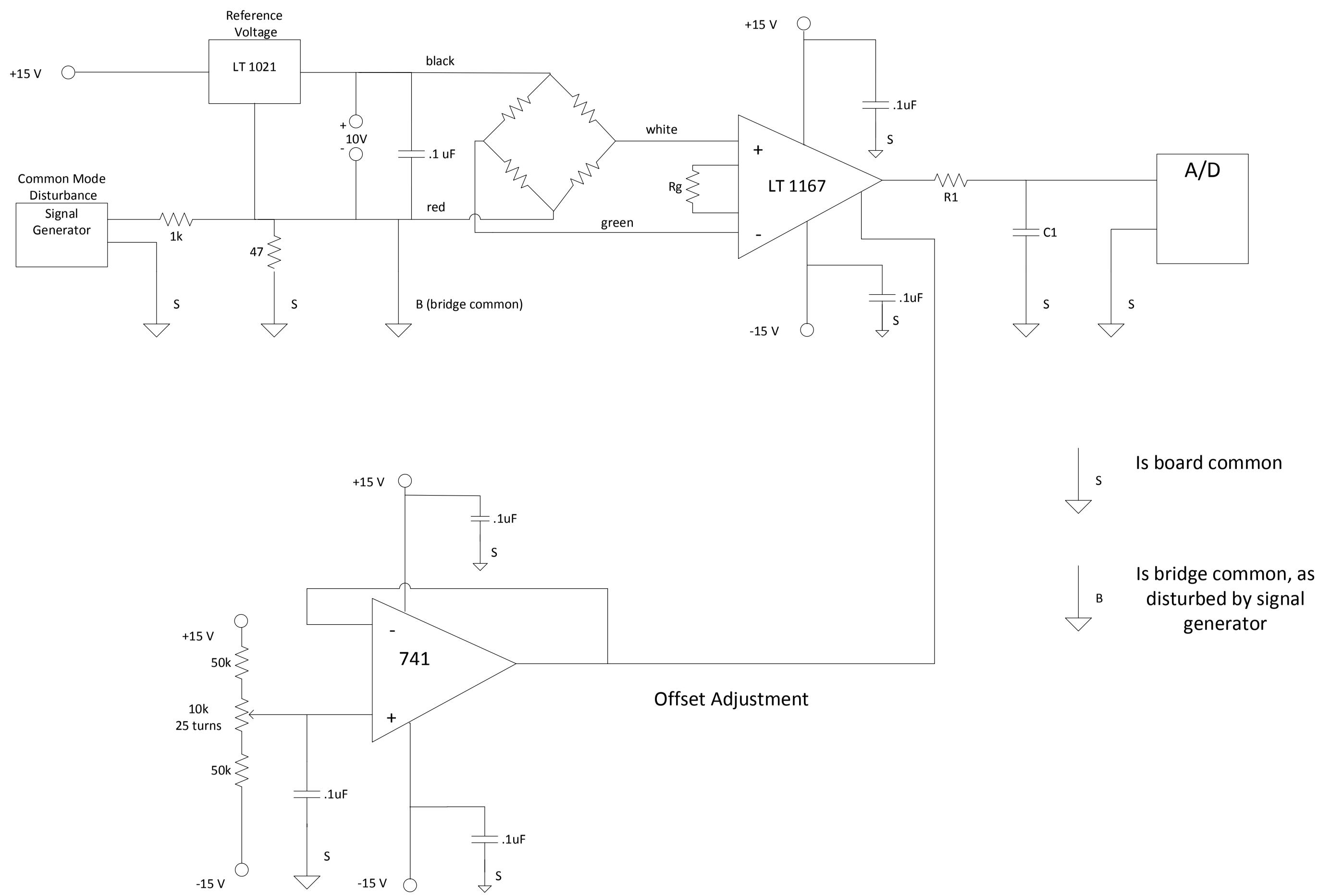

Figure 1: Scale interface circuitry

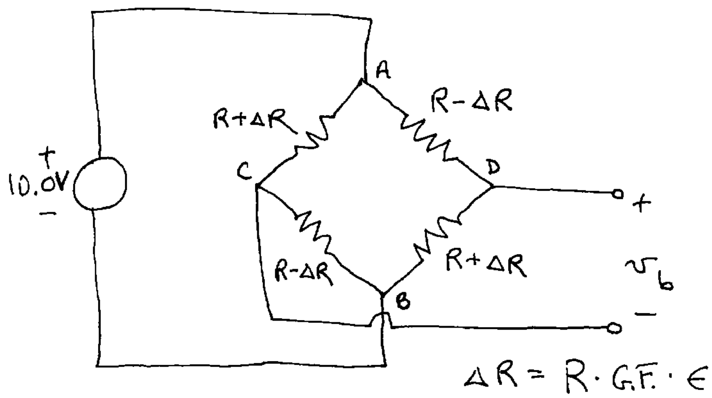

Figure 2: Full bridge circuit configuration.

5. **Low pass filter:** Design the low pass filter to have a breakpoint at about 50 Hz. Choose practical values of R_1 and C_1.

6. **Common-mode rejection:** Assume the nominal LT1167 Common-Mode Rejection Ratio (CMRR) versus frequency frequency response plot shown at the top of page 9 of the data sheet. Note that you will need to pick a curve appropriate to the gain value selected above. With respect to the scale circuit of Fig. 1, further assume that the signal generator input is a ±10 volt square wave. What is the predicted output versus time of the LT1167 amplifier under these conditions? You may assume that the 10 V reference has *perfect* power supply rejection ratio. That is, you may assume that the 10 V reference maintains exactly 10 V despite the common mode disturbance driven by the signal generator. What we are looking for here is the predicted step response of the amplifier circuit to the common-mode disturbance. Note that you will need to fit a dynamic model using the data given in the data sheet. Also note that the common-mode rejection ratio *drops* with increasing frequency, that is, the rejection is *worse* at higher frequencies. Your dynamic model will need to take this into account. Show your thinking and relevant calculations.

5 Lab exercises

1. **Circuit construction:** Build the circuit with the values selected in the prelab. Interface to the myRIO using the provided VI. Adjust the offset potentiometer so that the LT1167 output voltage is zero with no load. How close is your selected LT1167 gain value from the prelab, *i.e.*, how close is the LT1167 output to 9 V for 2 kg load? Adjust the scale factor in the VI so that the measured weight is accurately displayed. With this calibration, check the output versus weight for a number of different weights between 0 and 2 kg. What is the maximum percent deviation from linearity of your scale system?

2. **Scale dynamics:** Display the LT1167 output on the scope, *i.e.*, the voltage before low pass filtering. Conduct experiments to determine the natural frequency of the scale/weight system

as a function of the weight on the scale platform. Note that you will need to be careful to conduct the experiments so that the relevant mode is clearly seen, as there are many other possible modes. We have found it helpful to use a soft hammer like a rubber eraser block on the end of a pencil so that high frequencies are not inordinately excited. On the basis of your experiments, determine: 1) the scale platform stiffness [N/m], and 2) the scale platform no-load mass [kg]. Include relevant measured responses and show your thinking.

3. **Common-mode rejection using scope:** Connect two 10x scope probes to the bridge terminals C and D. Connect the signal generator to drive the common-mode disturbance input. Use a ± 5 V square wave from the signal generator to drive the resistive voltage divider which drives the bridge common. How large a disturbance does this induce on the bridge common? How is this reflected into the scope measured voltages on C and D? Configure the scope to subtract the two probe voltages. Can you see the effect of weight on differential scope voltage? With what resolution?

4. **Common-mode rejection using LT1167:** Connect a 1x scope probe (i.e., BNC cable) to the output of the LT1167. Now drive the common-mode bridge voltage using a ± 5 V square wave from the signal generator as before. What is the response observed at the output of the LT1167? How does this response compare with what you predicted in the prelab? Note that you will need to use the actual common mode voltage at the output of the resistive divider to compare with the rejection of the LT1167. How are the frequency-dependent dynamics reflected in this response?

5. **Minimum resolution:** What is the smallest weight difference that you can measure? Show us your approach and explain how you got the results.

6. **Optional:** Completely optional: Note that as configured we are only using the positive voltage range of the myRIO A/D converter. This throws away half the A/D resolution, since the negative range is unused. If you have time, reconfigure your circuit to use the full ± 10 V range of the A/D converter. Explain your approach and show us relevant results.